Supporting presentation for lecturers of Architecture/Civil Engineering

Chapter 11

Sustainability of Stainless Steels

Definitions

- **Greenhouse Gas (GHG)**: Emission Tonnes of CO_2-eq /Tonne Steel [1]
- **Global Warming Potential**: no unit Ratio of the abilities of different greenhouse gases (GHG) to trap heat in the atmosphere relative to that of carbon dioxide (CO_2) **[2]**. For instance, the GWP of Methane is **28 over a 100-year period.** The primary GHG emitted in the steelmaking is CO_2.
- **Primary Energy Consumption (GJ/T) GWP also called Energy Intensity** : The energy consumption required to produce 1 tonne of primary material (such as steel). [1]
- **Gross Energy Requirement (GER)**: is the total amount of energy required for a product. [8]
- **Materials Efficiency**: Measures the amount of material not sent for permanent disposal, landfill or incineration, relative to crude steel production. [1]

Definitions

- **Life Cycle Inventory (LCI)**: a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with the entire life cycle of products. (3)
- **Life Cycle Cost (LCC)**: is a tool for assessing the total cost performance of an asset over time, including the acquisition, operating, maintenance, and disposal costs. (4)
- **Life Cycle Assessment (LCA)**: is a tool to assist with the quantification and evaluation of environmental burdens and impacts associated with product systems and activities, from the extraction of raw materials in the earth to end-of-life and waste disposal. The tool is increasingly used by industries, governments, and environmental groups to assist with decision-making for environment-related strategies and materials selection.

Definitions

Safety Indicators:

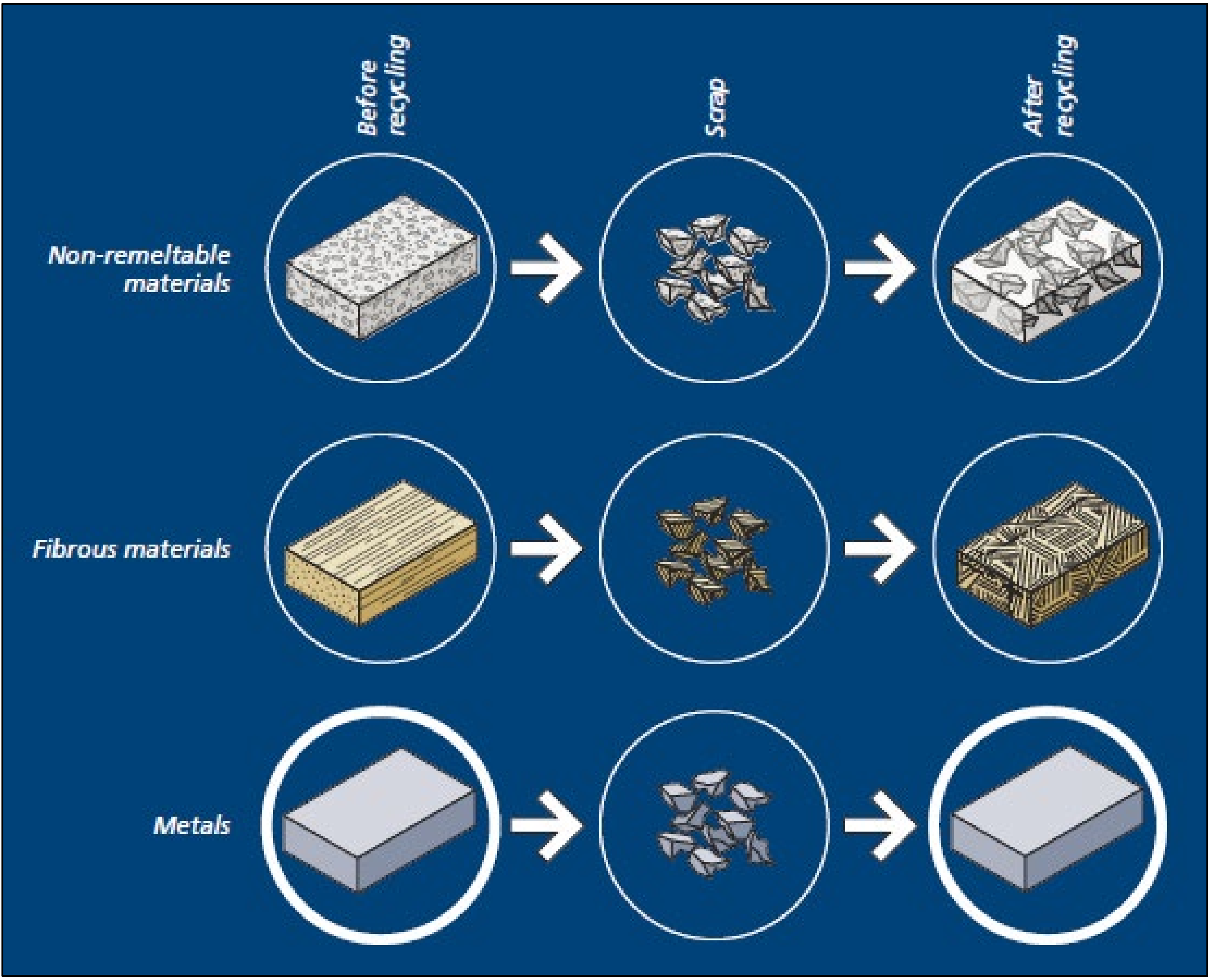
- **Lost–Time Injury**: The lost time injury frequency rate is the number of lost time injuries for each 1,000,000 working hours. (1)

Recycling Indicators:

- **Recycling rate** how much of the end-of-life (EOL) material is collected and enters the recycling chain (as opposed to material that is landfilled). (5)
- **Recycled content** is defined as the proportion, by mass, of post - consumer and pre - consumer recycled material in a product. (6)
- **Solid Waste Burden (SWB):** includes mining waste, tailings, slag and power station ash

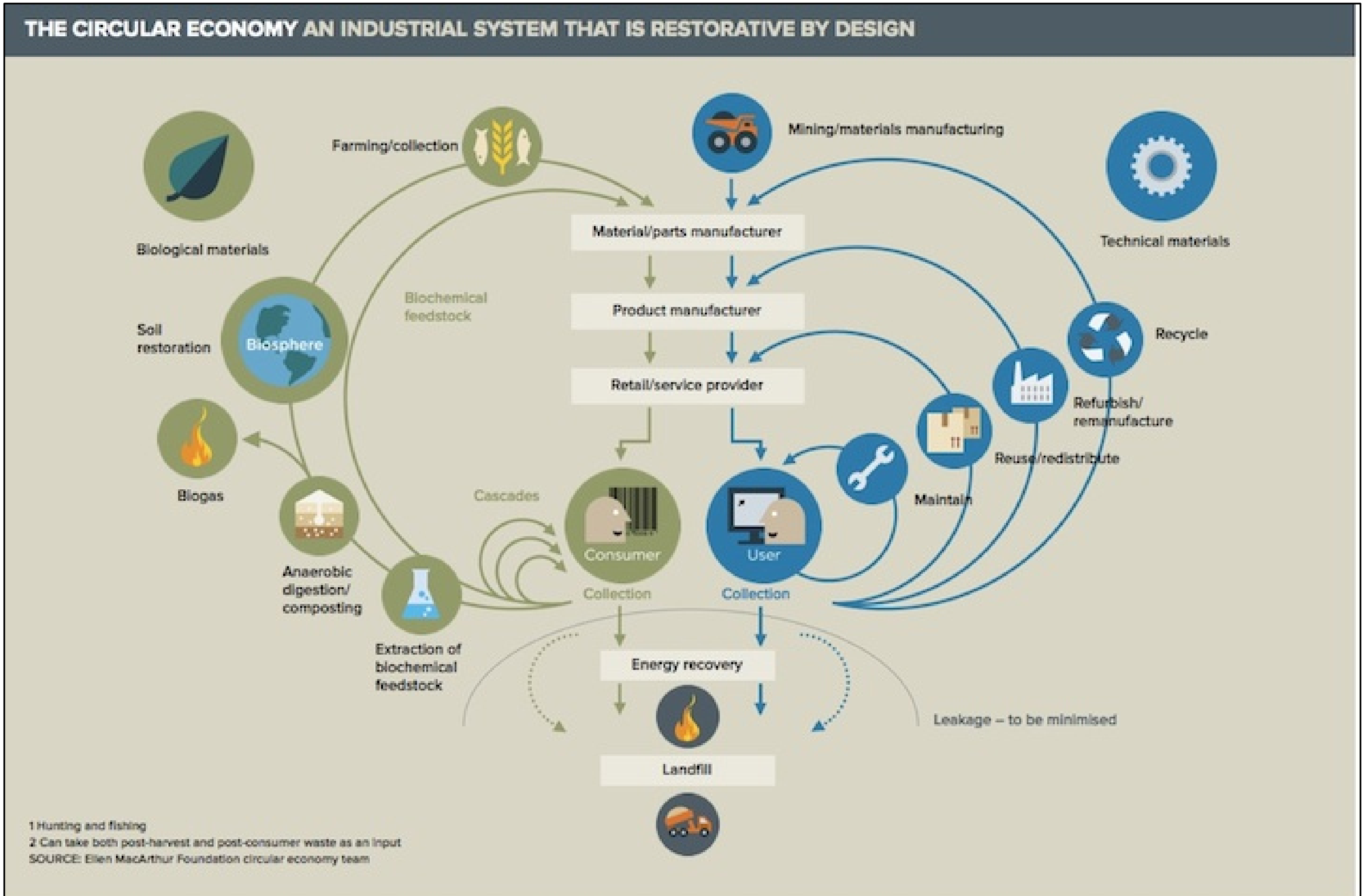
Comments on Indicators:

The recycling indicators do not take into account « downcycling».



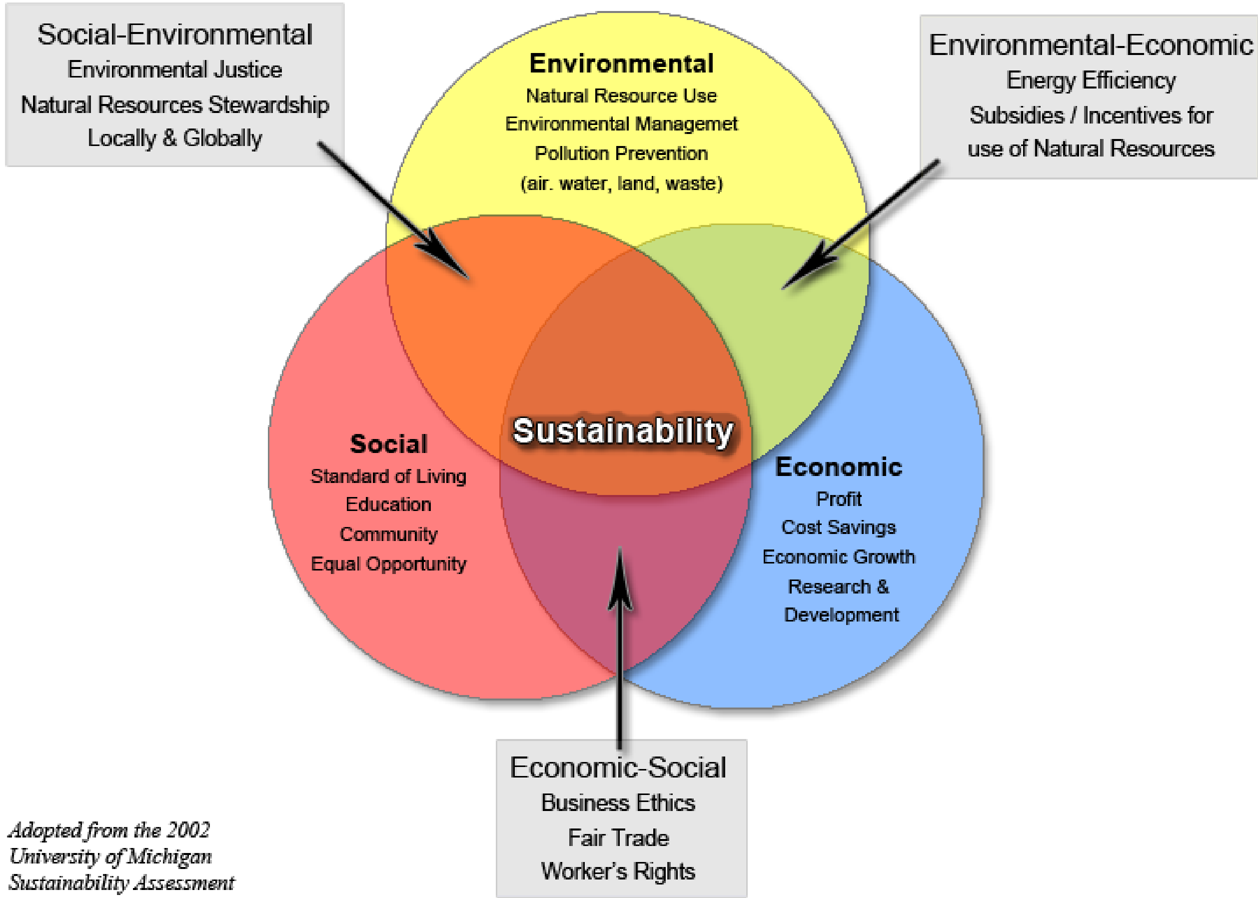
Metals can be recycled without loss of quality. Because metallic bonds are restored upon resolidification, metals continually recover their original performance properties, even after multiple recycling loops. This allows them to be used again and again for the same application. By contrast, the performance characteristics of most non-metallic materials degrade after recycling. (45)

Downcycling is better than waste but still a long way from Circular Economy (46,47)



Collecting scrap metal for new metal products is one of the shortest loops

Circular economy is all about closing resource loops, mimicking natural ecosystems in the way we organize our society and businesses.



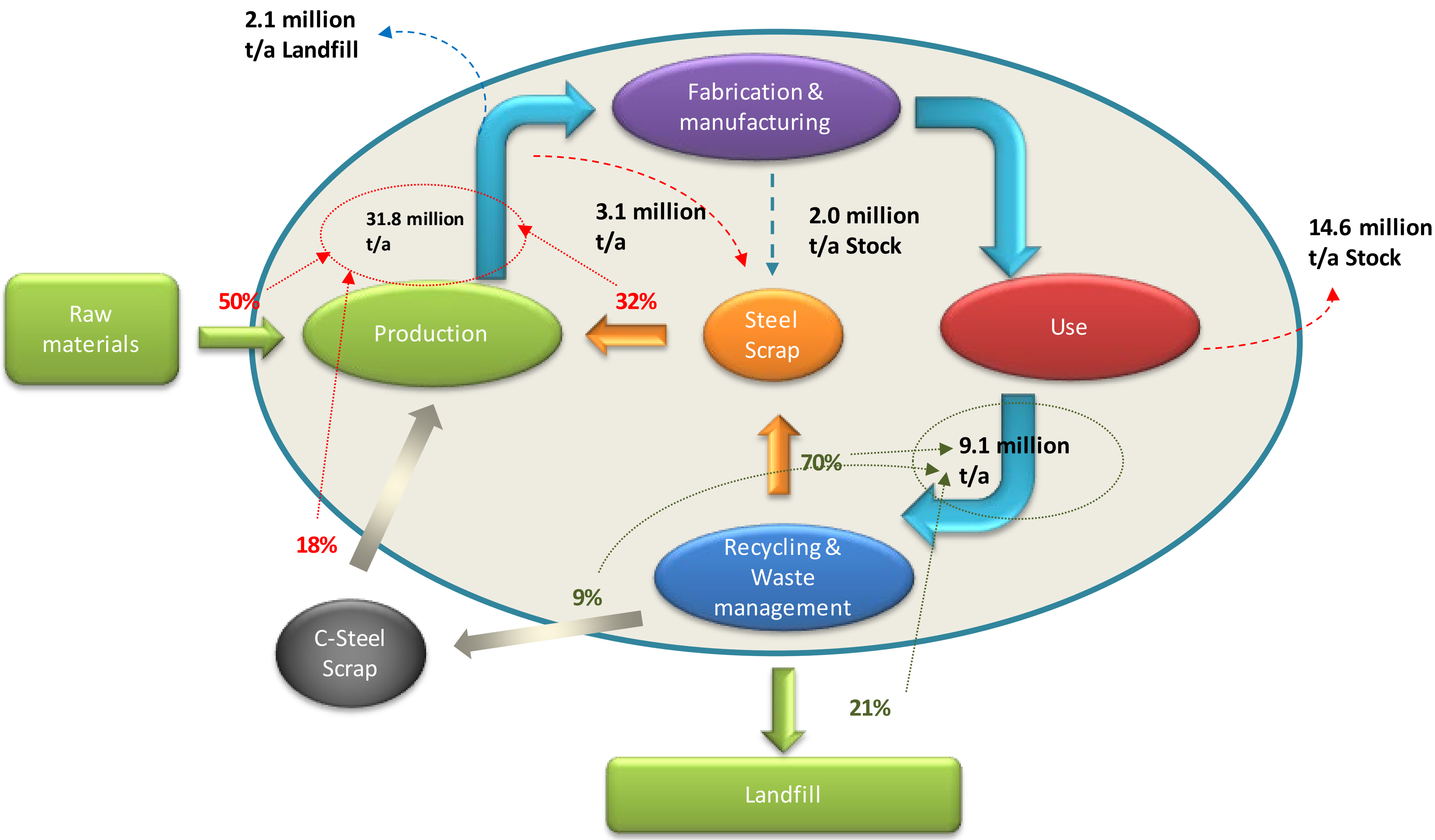
Sustainability

"Sustainability concerns the whole cycle of a product construction i.e. from raw material acquisition, through planning, design, construction and operations, to final demolition and waste management." (Rossi, B. 2012) [9]

Sustainability of stainless steel:

1. Environmental
2. Social
3. Economic

1. Environmental
Production ⇨ Use ⇨ Recycling [15]

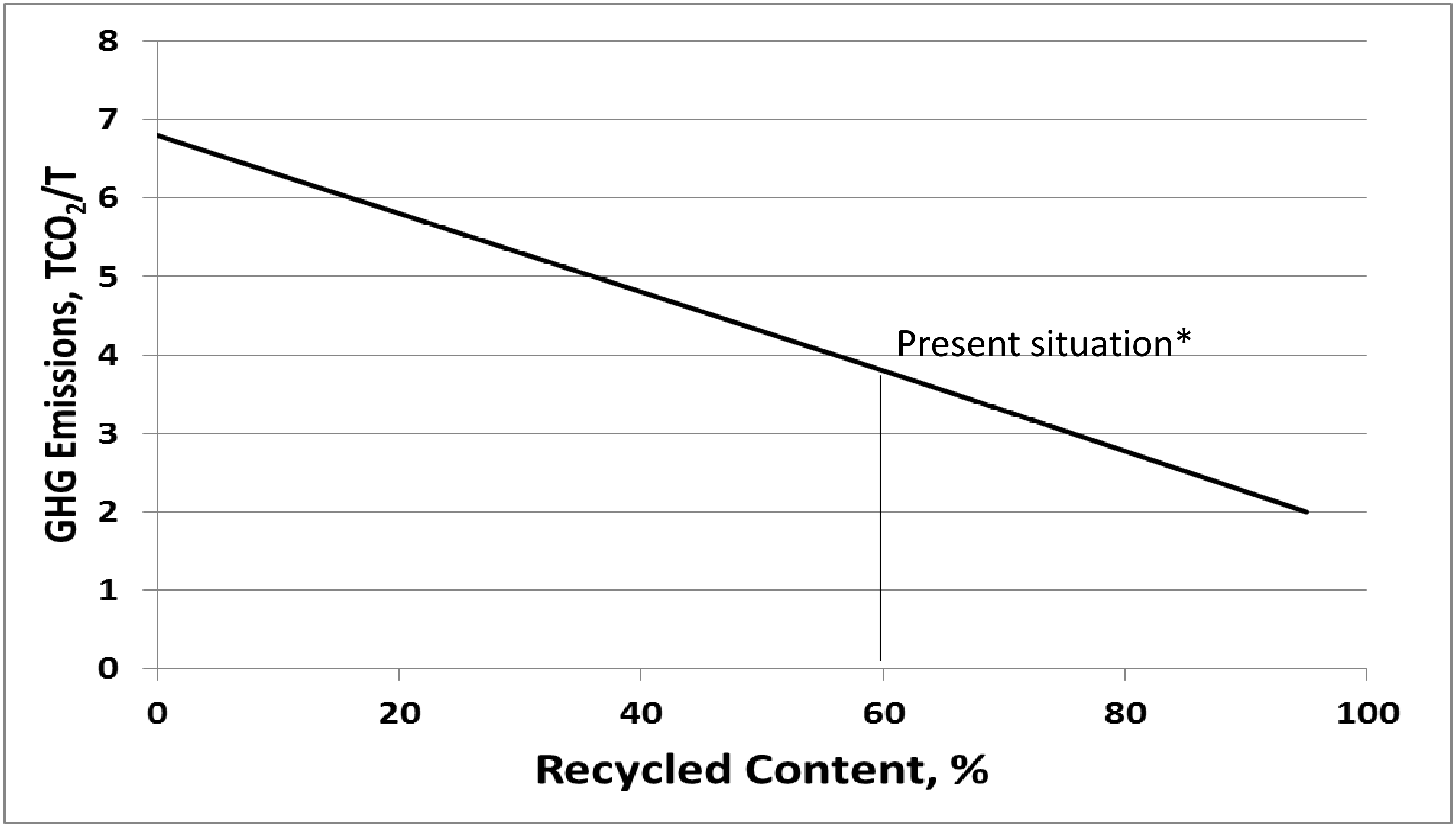


Life cycle of stainless steel in 2010. (YaleUniversity/ISSF stainless steel project 2013)

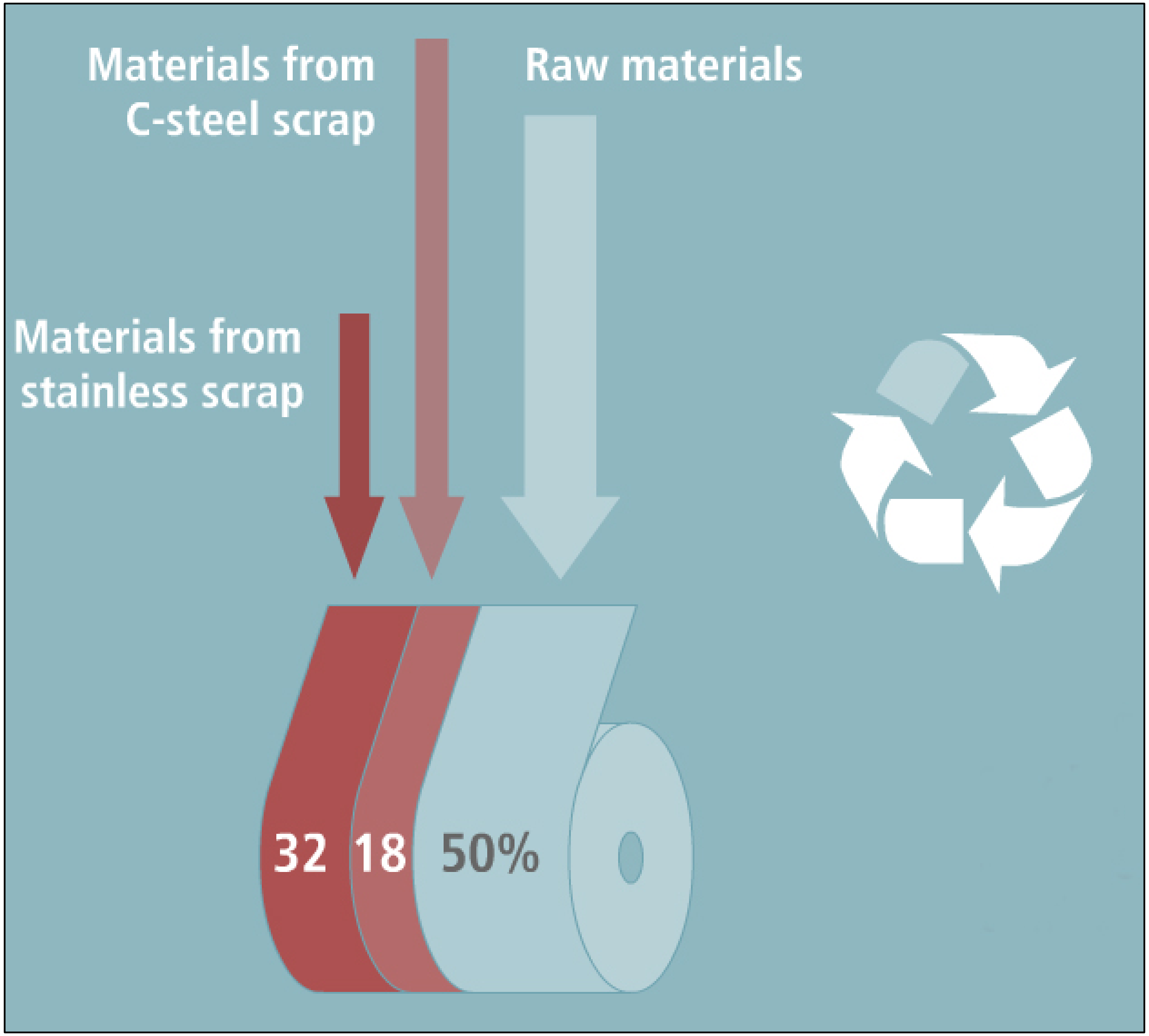
More on Use and Recycling [15, 23-25]

End Use Sector	Average lifetime (in years)	To landfill	Collected for recycling		
			Total	As stainless steel	As carbon steel
Building and infrastructure	50	8%	92%	95%	5%
Transportation (passenger cars)	14	13%	87%	85%	15%
Transportations (others)	30				
Industrial Machinery	25	8%	92%	95%	5%
Household Appliances and Electronics	15	30%	70%	95%	5%
Metal Goods	15	40%	60%	80%	20%

GHG Emissions vs. Recycled content [11, 12, 13, 14]



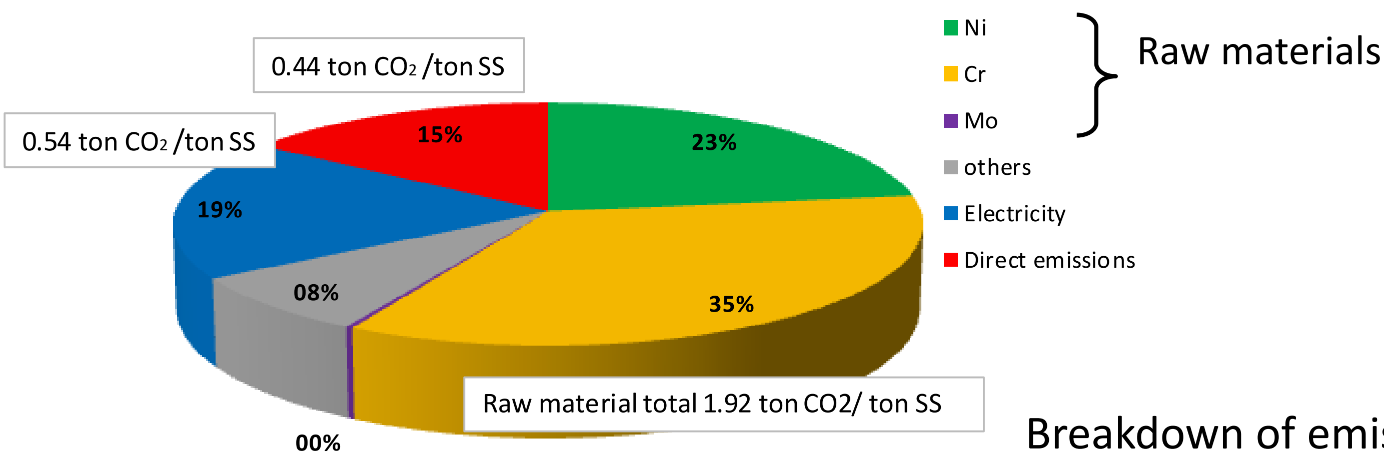
* The recycled content is limited by scrap availability



Recycled content of stainless steel

Greenhouse Gas Emissions for Stainless steel (15)

3.3 ton CO_2/ ton Stainless Steel (16)

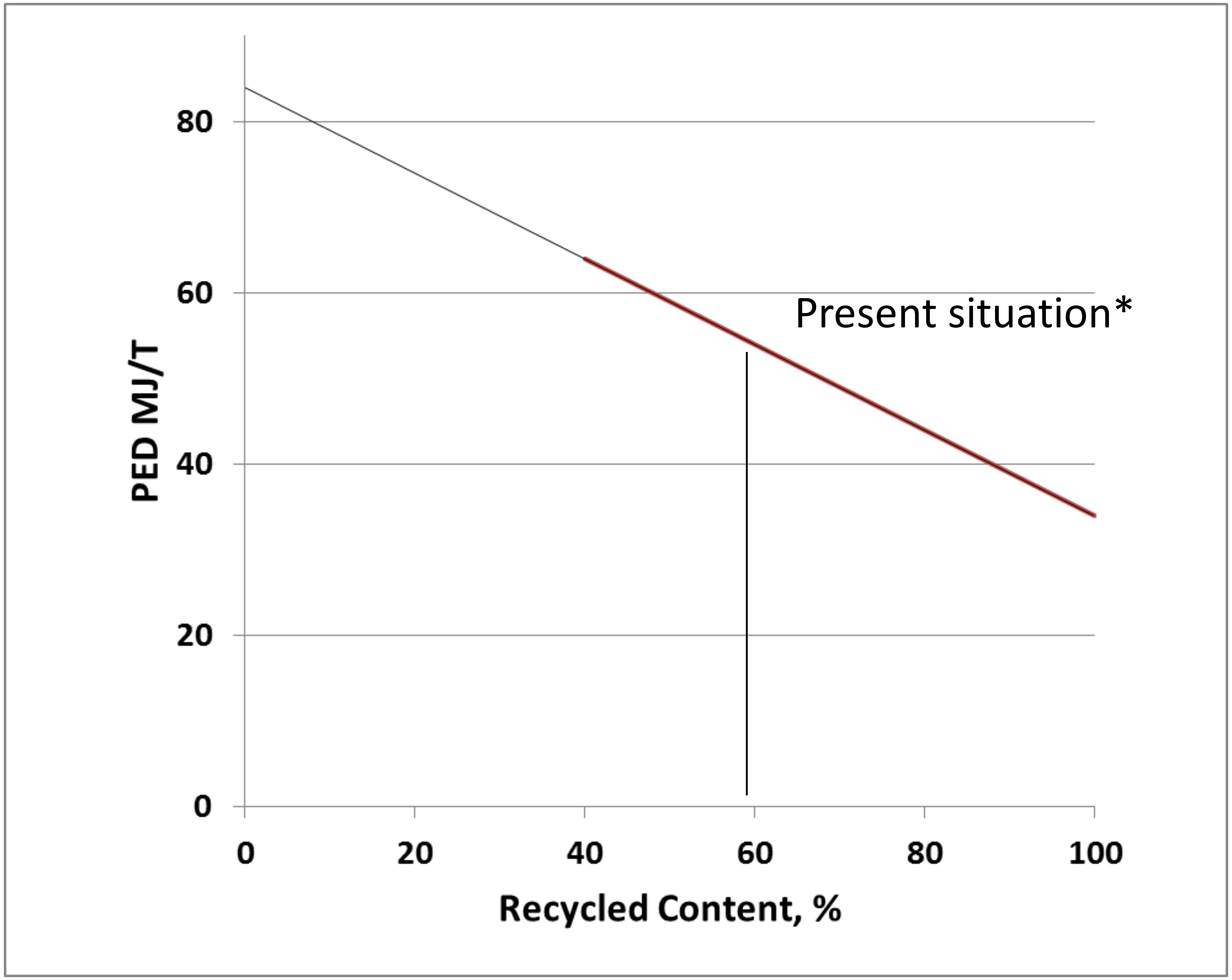


Breakdown of emissions:

- Raw Materials: ~58 %
- Electricity Generation: ~19 %
- Steelmaking: ~15% (17)

Note: This does not take into account Nickel produced by the Nickel Pig Iron Route, for which the figure for Ni is believed to be about 3 times higher. China is currently the only country using Nickel Pig iron

Primary Energy Demand [18]



* The recycled content is limited by scrap availability

Environmental impacts for "cradle-to-gate" metal production [19]

Metal	Process	GER (MJ/kg)	GWP (kg CO_{2e}/kg)	AP (kg SO_{2e}/kg)	SWB (kg/kg)
Stainless Steel	Electric furnace and Argon – Oxygen Decarburization	75	6.8	0.051	6.4
Steel	Integrated route (BF and BOF)	23	2.3	0.020	2.4
Aluminium	Bayer refining, Hall-Heroult smelting	361	35.7	0.230	16.9
Copper	Smelting/converting and electro-refining	33	3.3	0.040	64
	Heap leaching and SX/EW	64	6.2	-	125

GER: Gross Energy Requirement
Potential AP: Acidification Potential

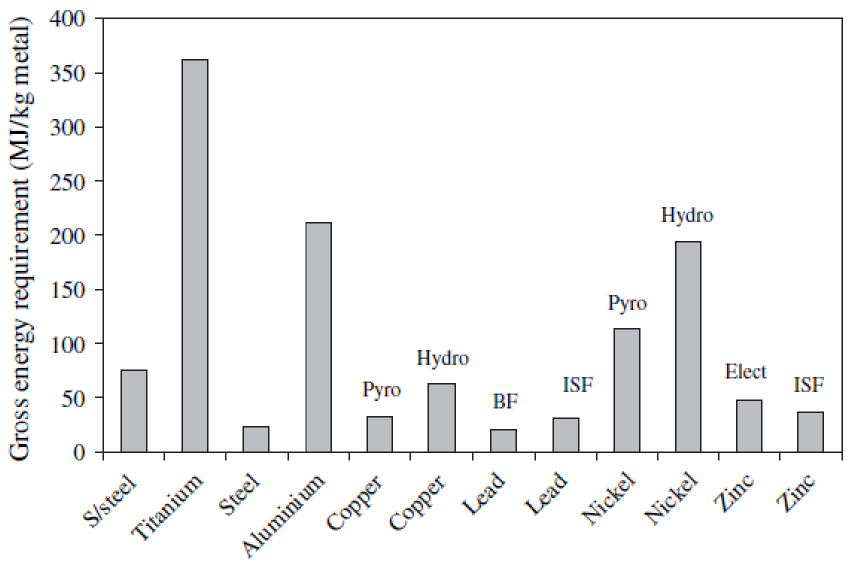
GWP: Global Warming
SWB: Solid Wast Burden

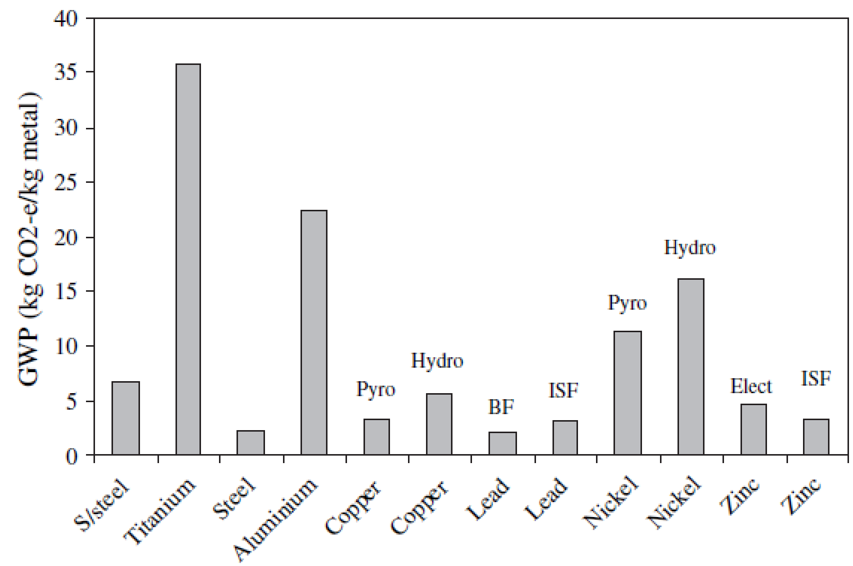
Environmental impacts for "cradle-to-gate" metal production[20]

Gross Energy Requirement for "cradle-to-gate" production of various metals

Global Warming Potential for "cradle-to-gate" production of various metals

(without any recycled content)





Materials are not used in the same quantity for a similar function or service [21]

Example:

Indicative environmental potential impacts for 3 different wall finishes.

Material	PED (MJ/m^2)	GWP ($Kg_{CO_2\text{-eq.}}/m^2$)	End-of-Life (EOL) scenario
High pressure laminate such as Trespa®	759.3	23.9	50% reuse + 50% landfill
Generic stucco	144.2	12.7	Not recycled
Stainless Steel 0.5mm	140.5	7.2	RR = 95%
Stainless Steel 0.8 mm	191.7	11.3	RR = 95%

Materials Efficiency

Reduce:

the quantity of raw material to produce Stainless Steel. (40%), consequently the CO_2 emission decreases.

Reuse:

The durability of stainless steels makes reuse very important.

Examples: Bottles, mugs, cups, straws…

Single use of plastics is increasingly banned

Example: Reuse [22]

The Stainless Steel panels had become dirty and scratched after about 50 years use. During renovation of the lobby, the 50-year old stainless steel panels were removed, cleaned, refinished and reused.

Materials Efficiency

Recycle:

Stainless Steel is 100% recyclable, all the scrap collected (82%) is reused.

Zero-waste stainless steel production ⇨ Slag and dust are the main by-products and waste which result from steelmaking. Example: Slag products can be used in the asphalt for road construction.

LEED* and Stainless LCI Data

- U.S. Green Building Council released “*Leadership in Energy and Environmental Design” version 4 (LEED v4) in 2013
  - New version includes changes that are favorable to stainless:
    - Greater emphasis on service life
    - Tighter requirements on VOC** emissions (a problem for some materials such as plastics)
- U.S. General Services Administration (manages US government buildings and properties) recently endorsed the use of LEED
  - State and local governments increasingly require LEED or similar certifications for new buildings or modifications

** VOC: Volatile Organic Compounds: for Stainless Steel, very small emissions during processing&fabrication (no data available yet) and none during use

Sustainable building with Stainless steel - The David L. Lawrence Convention Center, Pittsburgh (2003) [26]

Stainless steel roof:

- S30400 stainless steel
- Measuring: 280 × 96m
- Sheathed with 23,000m2 of 0.6mm (24-gauge), weighing about 136 tonnes.

Sustainable building with Stainless steel: the Gold LEED status

The Gold **LEED** (Leadership in Energy and Environment Design) status recognizes:

- the centre's brownfield redevelopment
- accommodation of alternative transportation
- reduced water use
- efficient energy performance
- use of materials that emit no or low amounts of toxins
- innovative design

Sustainable Civil Works with Stainless:
The Progreso Pier [27]

At Progreso, Mexico, a pier was built in 1970. The marine environment made the carbon steel rebar corrode – the structure failed.

Sustainable Civil Works with Stainless: The Progreso Pier

The neighbouring pier had been erected in 1937 – 1941 using stainless steel reinforcement.

Sustainable Civil Works with Stainless: The Progreso Pier

Ever since then, it has been maintenance free and remained in pristine condition.

2. Social

A sustainable material does not harm the people working to produce it, or who handle it during its use, recycling and ultimate disposal.

- Stainless steel is not harmful to people during either its production or use. For these reasons, stainless steels are the primary material in medical, foodprocessing, household and catering applications.

- The safety like injury-free and healthy workplace of the employees is the key priority for the stainless steel industry.

- Stainless steel also improves the quality of life by making technical advances possible. For example the installations that provide us with clean drinking water, food and medication would not be nearly as hygienic and efficient as they are without stainless steel.

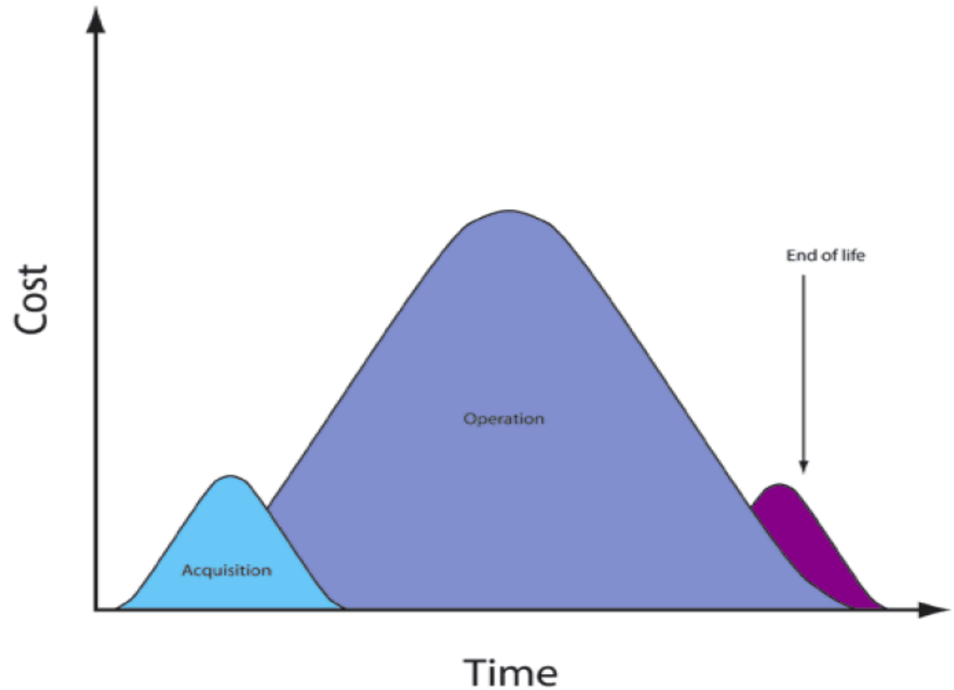
3. Economic


300,000
People directly or indirectly employed in the stainless steel industry worldwide
US$130 billion
Turnover of the global stainless industry, 2010
5,85% average increase in production each year since 1970
100% recyclable forever
45 million tonnes stainless steel fabricated in 2016

Life Cycle Costing (LCC) [30]

- LCC is the cost of an asset throughout its life cycle, while fulfilling the performance requirements (ISO 15686-5).
- LCC is the sum of all cost related to a product incurred during the life cycle:

conception ⇨ fabrication ⇨ operation ⇨ end-of-life



Source: Methodology of life cycle costing, European commission

Life Cycle Costing (LCC)

LCC is a mathematical procedure helping to make investment decisions and/or compare different investment options.

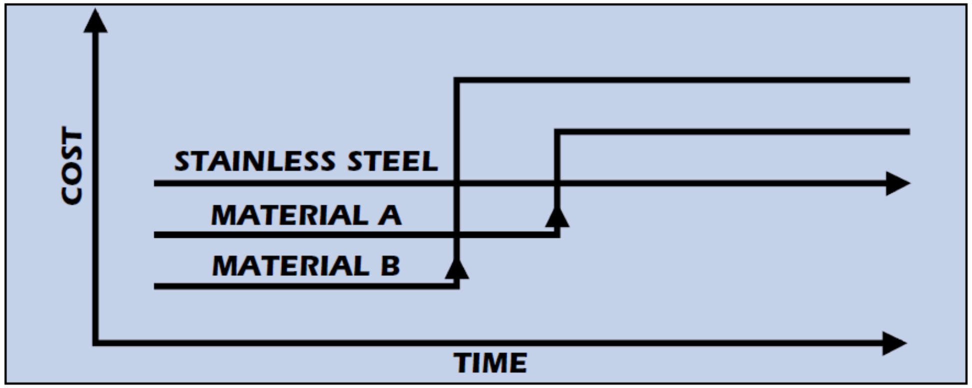
All Costs at Present Value Before Addition:

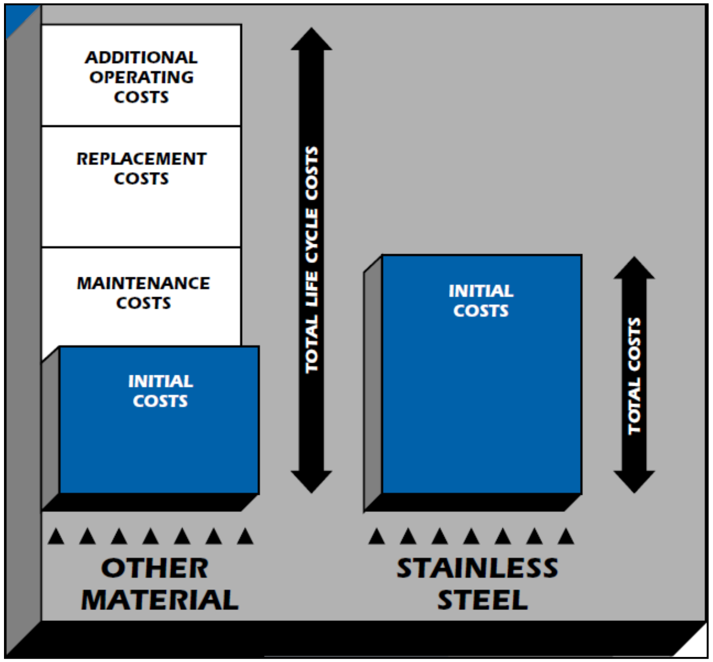
Total life cycle cost (LCC)		Initial materials acquisition costs (AC)		Initial materials installation & fabrication costs (IC)		Operating & maintenance costs (OC)		Lost production costs during down-time (LP)		Replacement materials costs (RC)
LCC	$=$	AC	$+$	IC	$+$	$\sum_{n=1}^{N} \frac{OC}{(1+i)^n}$	$+$	$\sum_{n=1}^{N} \frac{LP}{(1+i)^n}$	$+$	$\sum_{n=1}^{N} \frac{RC}{(1+i)^n}$

Where: **N** = Desired service life **i** = Real interest rate **n** = Year of the event

Stainless steel is not expensive if the life cycle cost is taken into account [31]

The cost of other materials substantially increases over time while the cost of stainless steel normally remains constant.

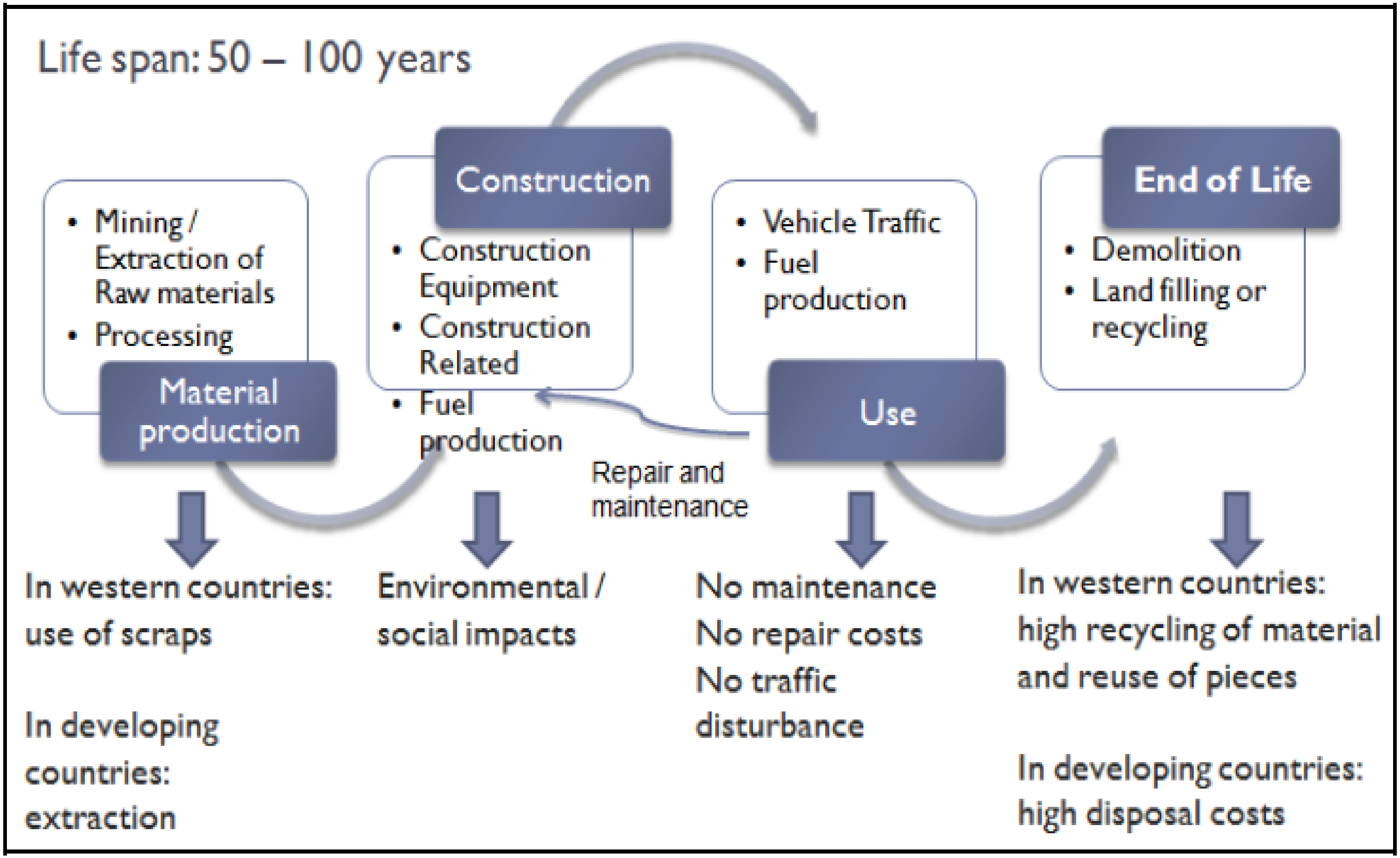




"Corrosion of metals costs the United States economy over $300 billion annually. It is estimated that about one-third of this cost ($100 billion) is avoidable by use of best known technology. This begins with design, selection of anti-corrosion materials like stainless steel, and quantifying initial and future costs including maintenance by Life Cycle Costing/LCC techniques. "

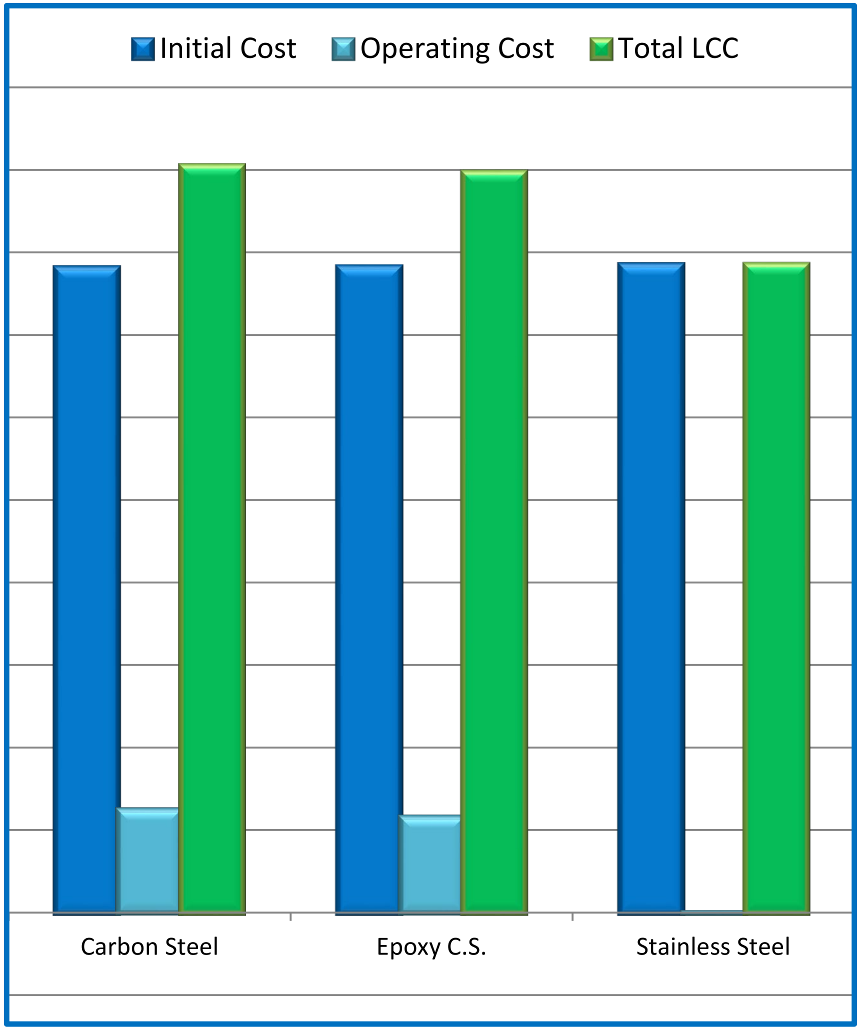
LCC Example: Bridges

Example of stainless steel bridge life cycle phases and its impacts on the environment in different areas of the world



LCC Example: Bridge

Life cycle cost summary of a reinforced concrete highway bridge [32]



Description	Carbon Steel	Epoxy C.S.	Stainless Steel
Material Costs	8,197	31,420	88,646
Fabrication Costs	0	0	0
Other installation costs	15,611,354	15,611,345	15,611,354
Initial Costs	15,619,551	15,642,774	15,700,000
Maintenance	0	0	0
Replacement	256,239	76,872	-141
Lost Production	2,218,524	2,218,524	0
Material related	0	0	0
Operating Costs	2,247,763	2,295,396	-141
Total LCC (USD)	**18,094,314**	**17,937,170**	**15,699,859**

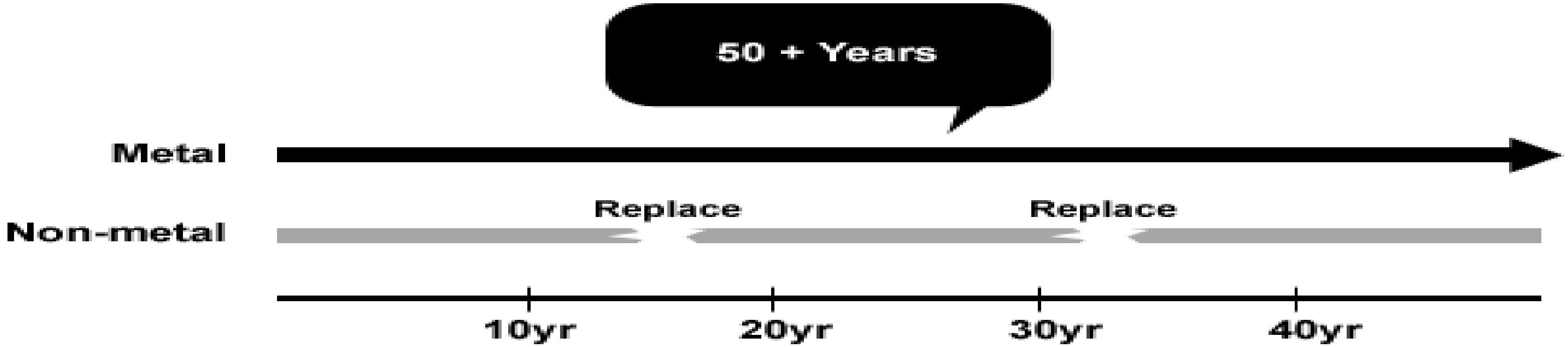
LCC Example: Roofing

Life cycle cost of a roof [33, 34, 35]

Conventional roofing systems, ~30 years

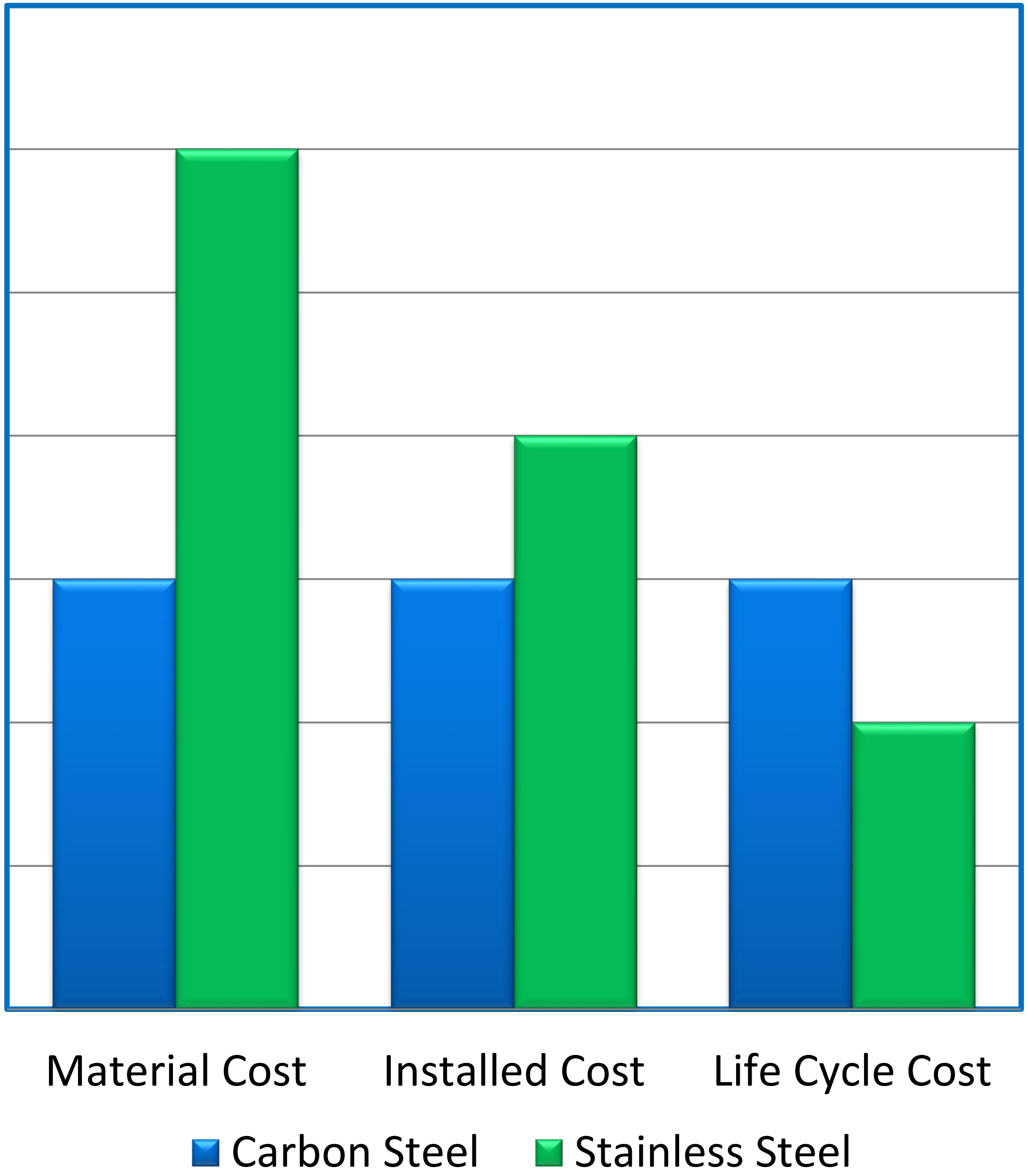
metal roofing system, 40-50 years

Stainless steel roofing system , more than 50 years



LCC Example: Roofing

Cost comparison of 0.6 mm coated galvanised carbon steel and 0.4 mm stainless steel grade 1.4401: Due to the mechanical properties of stainless steels, the material thickness can be reduced to 0.5 or 0.4 mm, providing a lighter weight (4,68 kg/m² for 0.7 mm coated carbon steel, 3,12 kg/m² for stainless steel). While coated carbon steel has a life expectation of 15 to 20 years, the service life of a stainless steel roof is generally that of the building.



Timeless Stainless Steel Architecture[43]

Savoy hotel, London, 1929

Empire State building, New York, 1931

Chrysler Building, New York, 1930

Helix Bridge, Singapore, 2011

Petronas Towers, Kuala Lumpur

Cloud Gate “Jelly Bean”, Chicago, 2008

Comparison of Life Cycle Costing [36, 37, 38, 39, 40]

Monument	Completed	Material	Height	Maintenance
Eiffel Tower – Paris 	1889 	Wrought iron	324m	Every 7 years. Every painting campaign lasts for about a year and a half (15 months). 50 to 60 tons of paint, 25 painters, 1500 brushes, 5000 sanding disks and 1500 sets of work clothes.
Chrysler Building (Roof and Entrance) – New York 	1930 (roof 1929) 	Austenitic Stainless Steel (302)	319m	Twice in 1951, 1961. The 1961 cleaning solution is unknown. A mild detergent, degreaser and abrasive were used in 1995.

What makes Stainless Steel **“Green”**?

Stainless Steel Environmental Evaluation [41]

What is the recycled content?	60%
Is it 100% recyclable?	Yes
Does it provide long life?	Yes (reduces maintenance and disposal frequency)
Is there recycled content?	Yes (both post-consumer and post-industrial)
Is construction waste diverted from landfills?	Yes (high scrap value and product reuse potential)
Can it be salvaged and reused during renovations?	Yes
Is it a low emitting material?	Yes (no coatings = zero emissions)
Can it help to improve indoor air quality?	Yes (no volatile organic compounds (VOCs), bacteria removal, corrosion resistant ductwork)
Does it help to avoid the use of toxic materials?	Yes (long lasting termite barriers, minimal roof run-off)
Can it save energy?	Yes (sunscreens, roofing, balcony inserts)
Can it help generate clean energy?	Yes (solar panels, power plant scrubbers)
Can it conserve water?	Yes (corrosion and earthquake resistant water lines and tanks)
Can reflective panels add natural light?	Yes
Can it extend the life of other materials?	Yes (stone and masonry anchors, fasteners for wood and metals sch as Al)

CONCLUSIONS

- Sustainability is a big and important challenge for the future in the stainless steel industry. Efforts has been done to reduce it Carbon footprint by increasing recyclability and improving processes.
- Stainless steel have a combination of properties which should be taking account in the decision making process at the design state:
  - Mechanical properties
  - Corrosion resistance properties
  - Fire resistance
  - Recyclability
  - Long life
  - Low maintenance costs
  - Neutrality and Hygienic
  - Aesthetics
  - Neutrality to rain water

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Thank you

Appendix
Recycling of other materials

This is a complex issue
This aims at giving a few ideas on other materials, for comparison purposes
Sources are indicated

More on recycling: Cement and Concrete

www.wbcsdservers.org/wbcsdpublications/cd_files/datas/business-solutions/cement/pdf/CSI-RecyclingConcrete-FullReport.pdf

- 20% maximum of crushed concrete can be used in new concrete.
  - as aggregates only, not as cement
  - the concrete thus produced is a lower quality product, not suitable for all applications
- It seems that most of the concrete after demolition goes into road beds and landfill (no detailed figures are available)
- Crushing old concrete and transportation are the main operations in recycling, to be compared with getting aggregates locally.
- 0verall, recycling involves everytime downcycling.
- Re-using concrete as blocks after demolition is only marginal today, but could provide the shortest route to re-use without downcycling. Not easy to implement, though!

More on recycling: plastics

http://www-g.eng.cam.ac.uk/impee/?section=topics&topic=RecyclePlastics&page=materials

- In-house scrap (generated at the source of production) is near-100% recycled already
- Recycling of used plastics is a big problem:
  - Collection is time-intensive, so expensive
  - Sorting of mixed plastic waste is difficult – contamination is inevitable.
  - Removing labels, print, all but impossible at 100% success rate
  - Contamination of any sort compromises re-use in "hi-tech" applications

=> recycled plastic (apart from in-house) is reused in lower-grade applications (downcycling): PET: cheap carpets, fleeces; PE and PP: block board, park benches.

=> and/or will be eventually burned or worse landfilled or even worse left floating on oceans.

More on recycling: Wood (from ABC*)

- The best recycling option is, of course, to re-use it. It appears that there is a lot of effort going on to collect, recondition and re-manufacture timber and other wood products. How much is re-used is not clear.
- Untreated timber and wood has found an increasing number of new uses: land and horticultural products, animal beddings, equestrian arena surfaces …
- Treated timber& wood (the chemical treatment prevents rot, fungi, insects and UV damage) contains harmful chemicals, which strongly limit their use. The largest use has been so far particle board manufacture, but what happens to these boards at their end of life remains unclear.
- It should be pointed out that the overall deforestation going on on the planet does not speak for unlimited sources of new wood, especailly in northern countries in which it takes a century for a tree to grow to its full size
- Cutting down a forest and re-planting trees leaves the topsoil open to erosion for a while, and destroys the ecosystem in the harvested area possibly beyond self repair.
- Last, it has been argued that the carbon neutrality has been achieved only when the re-planted forest is fully grown….some 30 years or more later!

https://dtsc.ca.gov/toxics-in-products/treated-wood-waste/

https://woodrecyclers.org/about-waste-wood/wood-recycling-information/

http://en.wikipedia.org/wiki/Wood_preservation

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*ABC: Architecture, Building and Construction

Thank you!

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